

# Comparative analysis on principles of TDM, WDM and TWDM multiplexing in passive optical networks

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**Abstract**—In the present article, a comparative analysis on principles of TDM, WDM and TWDM multiplexing in passive optical network in the exchange of information in communication networks is performed. Bandwidth, frequency bands and optical power budget of the optical cable line are considered. The results of the research can be used as a theoretical recommendation for selection and practical construction of passive optical network infrastructures.

**Keywords**—passive optical network, time division multiplexing, wavelength division multiplexing, hybrid passive optical network

## I. INTRODUCTION

The Passive Optical Network (PON) uses only passive optical elements and components in its construction: optical fibers, various types of detachable and non-detachable connectors, distribution and branch devices, attenuators, etc. The PON interface equipment consists of an Optical Line Terminal (OLT) located in the control center, an

Optical Network Unit/Terminal (ONU/T) at the terminal, and optical routers, e.g. optical splitters (OS - Optical Splitter), or WDM multiplexers/demultiplexers (Fig. 1) [1].

A passive optical network is a communication system that provides access to the last part of a telecommunications network that provides communications directly to users on the network. A PON network is a point-to-multipoint communication network that provides the transmission of information from an optical line terminal located in a central office (CO) over an optical distribution network (ODN) to optical network devices, located in the subscribers' side. PONs can also contain remote nodes (RNs) located between the OLT and the ONU, where many users are located.

The information for all users is transmitted simultaneously with time division multiplexing from the control center (OLT) to the transceiver optical network devices (ONT). Transmission and reception are performed in both directions, as a rule, on the same optical fiber, but at different wavelengths. In the

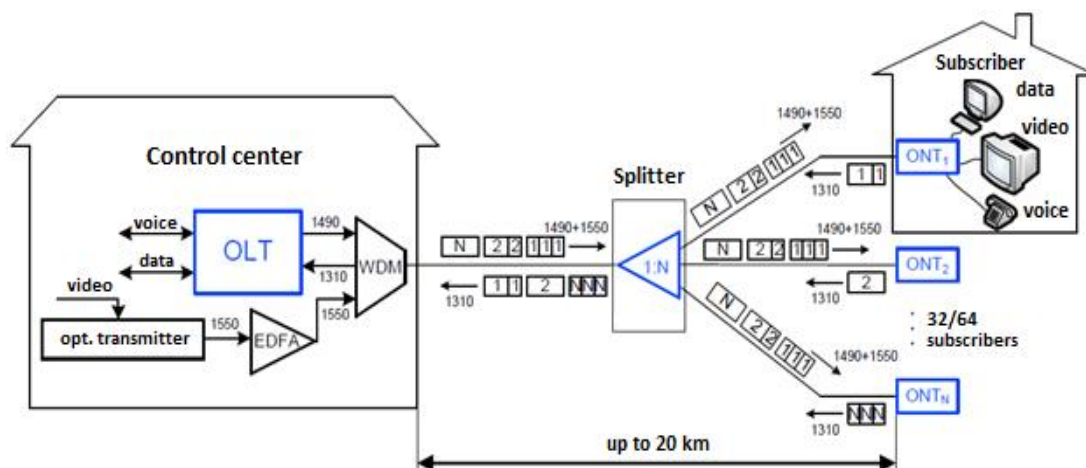


Fig.1. Passive Optical Network structure

transmission of upstream streams (from the subscriber to the station) the wavelength is 1310 nm, and in the downstream (from the station to the subscriber) - 1490 nm or 1550 nm. An optical WDM multiplexer is installed at the station side, which combines the transmitted signals of 1310 nm (voice, data) and 1550 nm (video). It is possible to connect a total of 32 (in some varieties - up to 64) subscribers with a maximum communication range of up to 20 km.

Each of the modern PON technologies has two operating modes - initialization mode and operating mode.

In the initialization mode started at the initial moment of the network operation, the OLT registers all available ONTs in the network, measures propagation delays to each of the ONTs in order to subsequently assign access intervals to each of the ONTs taking into account these delays. In addition, special procedures are used to equalize the power of transmitters of different ONTs. ONT clock generators are also synchronized. After all ONTs are registered, signal propagation delays are measured to each of the ONTs, the required transmitter power values are set, the clock generators of all ONTs are synchronized, and their clock systems are phased, the PON network switches from initialization mode to operating mode. In this mode, the OLT transmits information flows toward ONT, indicates by special messages to each of the ONT transmission interval, taking into account its position in the network and the required maximum bandwidth allocated by a special protocol.

The advantages of PON architecture are the following: high speed transmission, reduced maintenance costs, optimal use of the transmission medium, noise resistance and subscribers connect to the network quickly and without interruption of communication.

In recent years, time division multiplexing optical networks have been deployed around the world, such as gigabit-capable PON (GPON) and Ethernet PON (EPON) systems for multimedia applications. In TDM PON networks, the bandwidth is shared by multiple subscribers using a time division multiple access scheme.

PON wavelength division multiplexing (WDM) is considered as a promising solution for future broadband services. WDM PON networks can provide high-speed connections up to 10 Gb/s [2].

The latest step in the evolution of GPON networks is TWDM PON technology - passive optical networks with time and wavelength multiplexing. Hybrid TWDM PON networks combine TDMA and WDMA

## II. TIME DIVISION MULTIPLEXING (TDM PON)

TDM combines multiple low-speed input channels into one common high-speed channel. The input signals, in turn, modulate the high-frequency carrier signal for the set short time periods (time slots), which are periodically repeated. For example, during the first time interval, the carrier is modulated by the first input signal, through the second by the second, during the third by the third, during the fourth by the fourth, and so on (Fig. 2). In TDM systems, all data channels are transmitted on one fiber of the same wavelength at appropriate intervals.

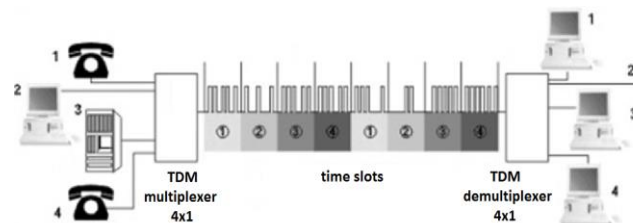


Fig.2. TDM multiplexing

The multiplexer on one side of the communication channel collects data from all sources and transmits it over the fiber through the appropriate time slots. The demultiplexer on the other side of the communication line divides time slots, reads the data and transmits it to the respective users in the form of single output streams.

The combination can be performed at the level of electrical and optical signals. When electrical signals are combined (Fig. 3), two series of pulses (there may be N sources) coming from inputs A and B are summed in a certain sequence of alternation in a group signal using a unifying device (UD).

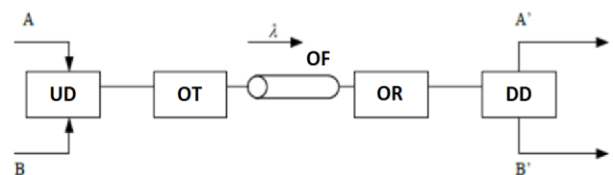


Fig.3. Principle of TDM multiplexing

The latter modulates the optical carrier in the optical transmitter. outputs A' and B'. Optical beam propagates along the optical fiber and is converted into an electrical signal in the optical receiver. This

signal is then split by a divider into two series of pulses, similar to the inputs, which are submitted to

The main advantage of TDM multiplexing is that one source of optical beam is required to transmit the multi-channel signal. In terms of bandwidth, time division multiplexing uses a narrower bandwidth. This makes it possible to increase the transmission speed (transmission speeds of 16 Gb/s and more have already been achieved experimentally).

The main disadvantages of PON systems with TDM are: with increasing transmission speed along the optical path it is necessary to use high-speed, complex and expensive multiplexers and demultiplexers in the terminal devices; time delays in signal propagation; information security issues [3].

### III. WAVELENGTH DIVISION MULTIPLEXING (WDM PON)

To optimize the existing TDM-PON concept, has been proposed the WDM-PON technology - wavelength division multiplexing. There are two main variants of WDM technology: high density (Dense WDM, DWDM) and low density optical multiplexing systems (Coarse WDM, CWDM). In the first case, the spectrum is divided into very narrow channels (of 0.8 nm), which, on the one hand, provides a large number of spectral channels, and on the other hand, significantly increases the cost of WDM equipment [4]. DWDM systems are mainly used in long-distance backbone networks. In urban access networks it is much more economical to use the second option - CWDM. In this case, the spectrum in the range from 1270 to 1610 nm is distributed over much wider channels - 20 nm each. The principle of application of this technology in PON networks is shown in Fig. 4.

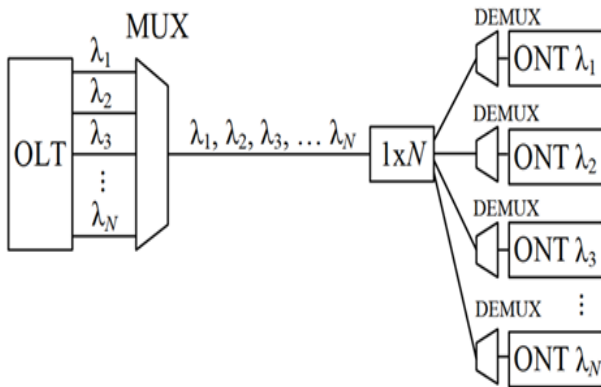


Fig.4. Principle of WDM multiplexing

The optical signals from N telecommunication systems with wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_N$  enter to an input of a passive wave multiplexer (MUX). The combined optical stream, in which all signals with the above wavelengths are present at the same time, passes into the transmission optical line. The received optical signal enters the wave demultiplexer (DEMUX), then is divided into output optical signals with wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_N$ , which are submitted to the individual telecommunication systems.

A second optical fiber or the same fiber for both directions may be used to organize the opposite direction of transmission.

The advantages of WDM multiplexing over TDM are the following:

- More efficient use of the wide bandwidth provided by the optical fiber, which leads to higher transmission speeds.
- Flexibility in creating access networks for random distribution of traffic of transmitted signals in different formats.
- Improve data transmission security by using different wavelengths for different subscribers.
- The average time delay for packet transmission (frames) in the WDM-PON segment is approximately 20 times less than for TDM PON.
- The average packet transmission time delay is not affected by the length of the optical lines and the number of subscribers.

### IV. HYBRID PASSIVE OPTICAL NETWORK (TWDM PON)

TWDM-PON technology uses four wavelengths as can be seen in Fig. 5, using TDM PON access mode in different spectral ranges to organize duplex communication channels. Each provider operates at a

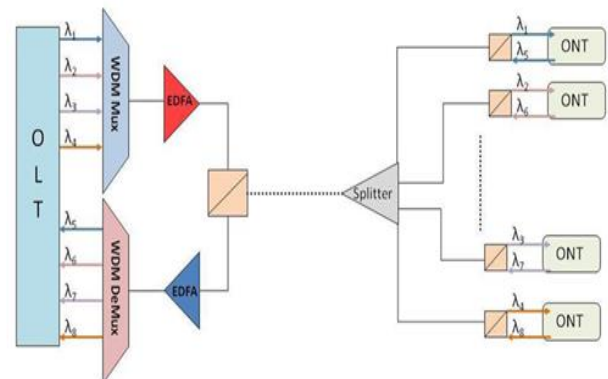


Fig.5. Principle of TWDM multiplexing



fixed frequency, processing requests from different ONT users using a time division protocol.

Wavelengths ( $\lambda_1 - \lambda_4$ ) are used to generate downstream, and four different wavelengths are used to transmit information in the upstream direction. Both symmetric 10 Gbps/10 Gbps, 2.5 Gbps /2.5 Gbps channels and asymmetric 10 Gbps /2.5 Gbps channels are supported [5].

In TWDM PON systems, three frequency bands can be used to transmit information streams: 1260-1280/1570-1580nm - XG-PON - band, 1535-1540/1553-1558nm - C-band, 1535-1540/1570-1580nm - C + L - band.

Due to the use of C-band wavelengths, it is possible to initiate standard EDFA optical amplifiers for DWDM networks with an operating range of 1529-1561nm. The optical amplifiers are installed on the side of the main station, which allows not to change the existing network architecture and not to initiate additional energy-dependent elements in the passive network.

If we compare the existing GPON systems with the TWDM PON technology, the following differences can be pointed out, according to which the TWDM technology is more promising:

- *Total system throughput.* For GPON systems the transmission speed is 10 Gb/s downstream and 2.5 Gb/s upstream, while in TWDM PON four independent streams of 10 Gb/s are formed, which determines the total bandwidth of the system - 40 Gb/s.

- *Frequency range.* GPON systems use two wavelengths to form a communication channel. At the same time, TWDM PON systems use four pairs of wavelengths with a rather narrow spectrum.

- *Optical power budget of an optical cable line.* Due to the impossibility to use optical amplifiers for GPON systems, the optical budget is limited to  $<30 \div 33$  dB, unlike TWDM PON systems, for which the optical budget reaches 38 dB.

Based on these distinctive features of TWDM PON, two main ways of applying such systems in practice are used.

The first envisages the gradual implementation of TWDM PON technology as part of the expansion of the existing network or during the construction of a new one.

The second way is to share a PON network from several operators or deliberately fragment the network of one provider.

### Conclusions

Analytical researches show that the WDM-PON network, despite its good transmission characteristics, cannot completely replace TDM-PON as the main network infrastructure in access networks due to its relatively high costs and complex techniques.

The prospects for the development of TWDM PON technology are very high, as the use of optical amplifiers and adjustable optical components allows operators to deploy and develop passive optical networks with maximum flexibility.

Administrators can choose the network development scenario that best suits their requirements. TWDM PON can co-exist with other PON technologies, enabling operators to develop and add new wavelengths to build new transmission channels in communication networks when the need arises.

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